Similarity of Homegarden Component Species and Their Genetic Distance between Tanzania and Indonesia

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SIMILARITY OF HOMEGARDEN COMPONENT SPECIES AND THEIR GENETIC DISTANCE BETWEEN TANZANIA AND INDONESIA

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ABSTRACT A field survey and genetic analysis were conducted to reveal the similarity and genetic distance between homegarden component species of Tanzania and Indonesia. Homegardens in the Uluguru Mountains in Tanzania and in Java Island in Indonesia were investigated in terms of land-use configuration and allocation of homegarden species. Samples of the major fruit species jackfruit (*Artocarpus heterophyllus* Lam.), mango (*Mangifera indica* L.), and banana (*Musa* spp.) were collected from the two areas and their genetic similarities were analyzed. The results indicated that homegardens in the Uluguru Mountains were similar to those in Java, particularly in terms of component species. Genetic analysis showed that jackfruit and most of the mango accessions in the Uluguru Mountains were distant from the Java accessions, but some mango accessions were similar to those of Java. Local use of the banana was diversified in Tanzania, and bananas exhibited greater genetic variation in Tanzania than in Java, despite Tanzania is far distant from the origin.

Key Words: Mango; Banana; Jackfruit; Homegarden species; Genetic diversity; Uluguru Mountains; Java Island.

INTRODUCTION

I. Historical Background of Coastal Tanzania through Trans-Indian Ocean Trading

Trans-Indian Ocean areas have been closely linked since ancient times, when trading and migration were conducted with the trade winds and ocean currents. Through maritime trading, many plant species have been disseminated to coastal areas of East Africa from Southeast Asia, India, and the Middle East (Beaujard, 2011). The Tanzanian coast, an entry portal to East Africa, was developed as a hub port for trans-Indian Ocean trading during the 7th century (Boivin et al., 2013). Tanzania has strong relationships with nations bordering the Indian Ocean, including Arabian, South Asian, and Southeast Asian countries.

The East African coast developed as a base for trans-Indian Ocean trading before the Common Era. In the 7th century, Islamic culture reached this area via visits by Indian and Arabic traders (Tominaga, 2001). Intermixing of Islamic culture from Arabia with the indigenous culture of Africa via trans-Indian Ocean trading resulted in development of Swahili culture. At present, the majority of coastal Tanzanian people are Muslim, as is the survey area in the Uluguru Mountains.

Before the control by the Sultanate of Oman started, trans-Indian Ocean trad-

ing had expanded and developed. The Portuguese dominated the trading during the Age of Discovery in the late of 15th century to the 17th century, although Arabic power especially from Oman reconquered the East African coast and established the capital of Zanzibar under the Al Said dynasty in the middle of the 19th century. During these periods, trans-Indian Ocean trading accelerated. Zanzibar at that time was a terminus for slave trade caravans from the interior of Africa. Such trade and travel from regions along the Indian Ocean, including Southeast Asia, exerted significant effects on coastal Tanzania. In addition, trading by European people, including the Portuguese, likely resulted in the introduction of spice crops to the East African coast.

II. Overview of the Uluguru Mountains

Uluguru Mountains

Our survey area in the Uluguru Mountain range (Fig. 1), which is 200 km inland of Dar es Salaam, the primate city in Tanzania, was affected by trans-Indian Ocean trading and was introduced with many exotic plant species. The Uluguru Mountains are in Morogoro Region, south of Morogoro city. The highest mountain peak is 2,630 m above sea level (asl). The Luguru people reside below 1500 m asl, and above this altitude, the mountains have been designated a conservation area to preserve the natural forest and indigenous habitats (Photo 1).

Morogoro is connected to more inland cities such as Dodoma, Iringa, and Mbeya on the trading route from the coast. Morogoro has long been an important stop for inward-trading traffic. Before the end of the 19th century, the trade route reached Lake Tanganyika and then continued further to Congo and Zambia, and supported the slave and ivory trades (Iliffe, 1979). Thus, the Uluguru Mountains and the surrounding areas were closely connected to the coastal city Bagamoyo or subsequently to Dar es Salaam and Zanzibar Island, serving as a port of entry from the Indian Ocean and a center of trade between coastal and inland areas.

The temperature at altitudes between 500 and 1,500 m is higher than in temperate zones, and annual rainfall is much higher than in the surrounding lowland. Thus, cultivation of tropical crops is facilitated by the abundant precipitation and warm temperature. The Luguru people cultivate annual subsistence crops such as maize, taro, rice, and other starch crops (e.g., sorghum, cassava, and breadfruit tree) as their staple foods on the crop fields. They also cultivate cash crops, including various fruits such as banana, jackfruit, mango (Photo 2), and spices such as cinnamon, cardamom, pepper, and clove, in their homegardens (Higuchi et al., 2011). Banana is the most important cash crop and is cultivated in the homegardens of all households. Its cultivation accelerated after the 2000s when banana wholesale markets were established at the foot area of the mountains. Many fruit and spice crops are planted together with local vegetables, including African eggplant (*Solanum aethiopicum* L.) and Malabar spinach (*Basella alba* L.). Therefore, the landscape of the Uluguru Mountains is characterized by diversified and multi-layered homegardens (Photo 3).

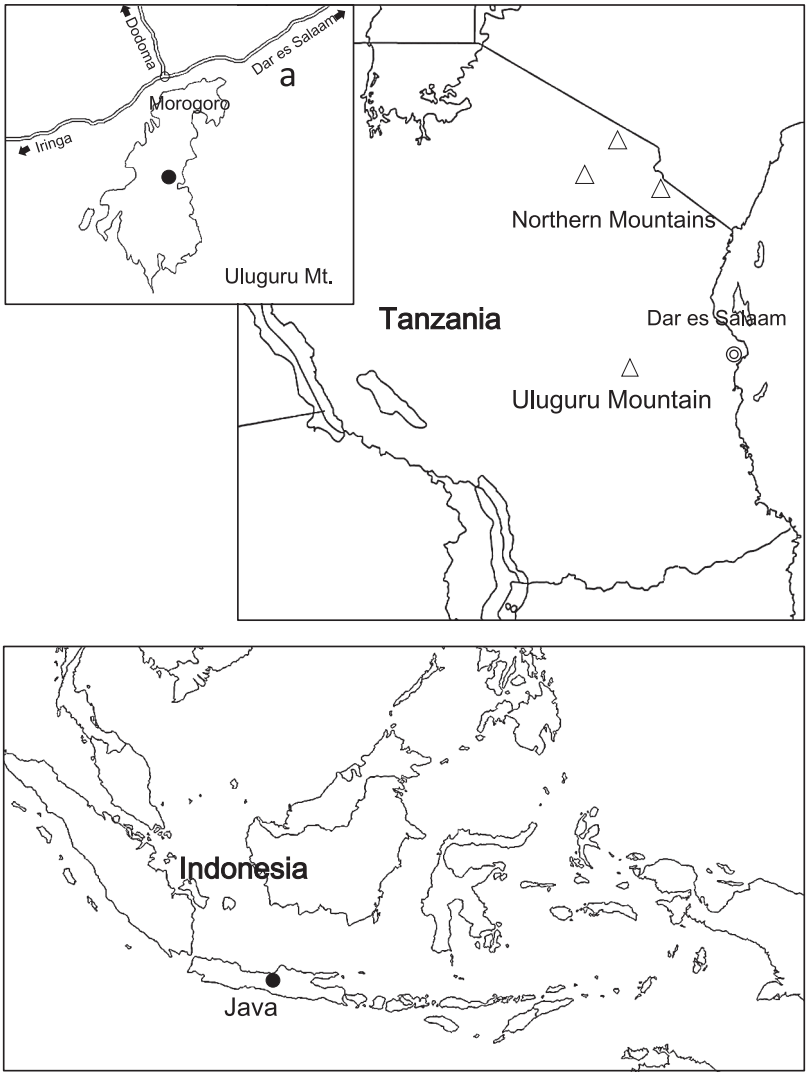

Fig. 1. Survey areas in Tanzania and Indonesia

III. *Jalala*, the Homegarden System of the Uluguru Mountains

The homegarden system in the Uluguru Mountains is known locally as *jalala* (Higuchi et al., 2011), which linguistically is of Arabic origin and means "dumping place". Some kitchen waste is indeed dumped here, but it is not merely a dumping place. The terminology *jalala* is a kind of declaration to cultivate perennial crops which the homegarden owner wants, including especially fruit and spice trees. This declaration is a result of the Luguru traditional land tenure system which states that crop fields cannot be inherited by the user's descendants directly.

Instead, the land must be handed over to another member of the clan according to the clan's decision; the land is owned by the clan and is returned to the clan after the death of the current land user (Higuchi et al., 2011). Thus, planting of perennial crops is hesitated because crop ownership belongs to the individual villager who planted the crops, and long life perennial tree crops may cause ownership problems after the death of planted person, resulting in a conflict with the traditional land tenure system. Accordingly, *jalala* came to be interpreted more broadly from its original meaning to cultivate perennial crops including fruit and spice trees, which are vital for their livelihood. A typical land use by *jalala* is shown in Photo 4 where all trees are planted tree crops and natural trees are not remained, although the landscape retaines the appearance of a natural forest and the roofs of the houses are covered with its canopy.

Banana, mango, jackfruit, breadfruit, coco palm, cinnamon, clove, and other crops are cultivated in *jalala* (Photo 4). Most of these trees originate in Asia, whereas they are rare in Africa. Thus, the landscape of *jalala* possibly resembles that of Asian homegardens. However, no comparative research has examined the genetic similarities of homegarden species between tropical Asia and East Africa. Although the function of *jalala* in local agriculture was studied in detail by Higuchi et al. (2011), no comparison with other areas has been made.

Homegarden composition and plant use in Java in Indonesia have been well investigated, which allows comparisons with *pekarangan*, the homegarden system in Java. For example, Arifin et al. (1997) surveyed west Java *pekarangan* and reported that mango and banana are often cultivated together with vegetables and ornamental plants, and that urbanization increases the proportion of ornamental plants in homegardens. Arifin et al. (1997) also noted that *pekarangan* crops are mostly cultivated for self-consumption, with the surplus usually sold at local markets. *Jalala* in the Uluguru Mountains is similar to *pekarangan* in Java, at least with respect to external appearance.

IV. Objectives

Jackfruit, mango, and banana are commonly found in tropical homegardens in Asia and Africa. Jackfruit propagates by seeds. Banana propagates vegetatively. Mango can propagate by seeds and also by grafting in the case of established cultivars. Genetic differences among jackfruit trees from different locations generally tend to reflect geographic distance; if this tendency is not obtained by the genetic analysis, it implies that some artificial interventions have been caused to the distribution process. Vegetative propagation of banana indicates dissemination of preserved genes or staged variation according to the distance. Modern commercial mango cultivars are propagated by grafting, whereas old trees are grown from seedlings. Thus, both patterns are seen in mango. Use of these fruit trees for genetic analyses allows the detection of genetic similarities and differences, and facilitates assessment of fruit crop dissemination and genetic continuity over large distances.

In the present study, we recorded and compared the plant species found in *jalala* and *pekarangan*. Three common fruit species—jackfruit, mango, and

banana—were subjected to genetic analysis to elucidate their use and dissemination history.

SURVEY AREAS

I. Uluguru Mountains

Tanzania is an East African country located near the equator. Our survey area in the Uluguru Mountains is located at a latitude of 7° south. Most of the country is covered with tropical dry savanna, and an annual precipitation is less than 600 mm. Regular droughts impair agriculture, except for in the Lake region, Northern highlands, and mountainous areas in coastal regions where the trade winds from the Indian Ocean bring in humid air.

Survey was conducted in lower Kibogwa on the eastern slope of the Uluguru Mountains at 600–900 m asl, which is an area characterized by a mean annual precipitation of 1,500 mm. The precipitation increases to 3,500 mm in the forest reserve along the top ridge of the mountains. Most of the people in the survey area are Muslim, as a result of the infiltration of Islam.

II. Northern Mountains

North Pare, Kilimanjaro, and Meru mountains were selected as sites for the collection of samples of jackfruit, mango, and banana leaf. Local people were interviewed on their plant use. Banana and jackfruit are often grown at higher elevations (1,000 m asl). Mango trees are grown at lower elevations because of their drought tolerance, although this tree can also grow at higher altitudes.

The North Pare and Kilimanjaro mountains are inhabited by the Pare and Chagga peoples, respectively. Most Chagga are Christian and most Pare in North Pare are Muslim. Both groups of peoples intensively cultivate banana as their staple crop (Lawrence, 2009). Generally, banana is produced in their homegardens, known as *kihamba* in the Chagga language (Fernandes et al., 1984; Rugalema et al., 1994). *Kihamba* contains usually only a few plant species; coffee is cultivated as a cash crop under the shade of silky oak (*Grevillea robusta* A. Cunn. ex R. Br.) or banana plants. Therefore, we collected banana samples from *kihamba*, and mango and jackfruit samples from trees growing along the street or beside crop fields.

III. Java

Homegarden surveys and sample collection for genetic analysis were also conducted in the western and central regions of the island of Java (Fig. 1). Java is the main and most densely populated island in Indonesia, and land use there is intensive. Java is located within the Indian Ocean, at a latitude of 7° south, as is the Uluguru Mountains. Java is a mountainous island with a humid climate, which again is similar to that of the Uluguru Mountains. Western and central Java

are more humid than east Java. Thus, we conducted our survey in western and central Java, where the *pekarangan* homegarden system is well developed.

Many tropical fruit species, including banana, durian, rambutan, mango, and salak palm, originated in Southeast Asia. Jackfruit originated in Bangladesh and considered to be a center of genetic diversity, although Java is also considered to be the second center of the diversity. Jackfruit is the national fruit of Indonesia.

The Austronesian language family started from Insular Southeast Asia (including Java) arrived Madagascar before the 7–8th centuries along the trade winds and excellent sailing navigation skill (Beaujard, 2011). In the 15th century, people from East Asia, India, and West Asia travelled to Java, which was the center of a trading network; people even traveled from Europe to Java in search of spices. Many sultanates were founded in the 16th century, which is why the majority of the population of Java is Muslim.

HOMEGARDEN SURVEY AND DATA COLLECTION

I. Similarity of Homegardens between East Africa and Southeast Asia

For the survey, eight households in 2014 and 18 in 2016 on the eastern slope of the Uluguru Mountains were visited and their homegardens were surveyed. In Java, eight households were surveyed in 2014. Local names, numbers of individuals, and sizes of the plants were recorded. Potted and ornamental plants were omitted, because this study focused on perennial and woody plants. The location of each plant species in the homegardens were recorded by drawing top-view sketches and taking photographs with a 360° camera. Plant diversity of each homegarden was determined by calculating the Shannon–Wiener diversity index (*H'*) (Shannon, 1948).

II. Collection of Fruit Crop Samples for Genetic Analysis and Plant Use Survey

1. Sample Collection

Leaf samples were collected from jackfruit, mango, and banana and plant use was surveyed in Tanzania and Indonesia in 2016. The homegarden owner or their neighbor was interviewed to obtain information on local plant use. In total, jackfruit samples of 37 accessions were collected from the Uluguru Mountains (12 accessions), Northern Mountains (13 accessions), and Java (12 accessions) (Table 1). Two accessions of Indonesian jackfruit, four commercial cultivars, and one cempedak species (*Artocarpus integer* (Thunb.) Merr.) grown at Kyoto University, Japan, were used for comparison (Table 2). In total, 29 mango accessions were sampled from the Uluguru Mountains (5 accessions), the Northern Mountains (3 accessions), and Java (21 accessions) (Table 3). Six commercial cultivars and three wild mango accessions (*Mangifera pentandra* Hook. f.) maintained at Kyoto University were used for comparison (Table 4). In total, 59 banana accessions were sampled from the Uluguru Mountains (12 accessions), the Northern Mountains (33 accessions), and Java (14 accessions) (Tables 5 and 6).

Table 1. Leaf morphology of jackfruit

Location	Sample ID	Leaf characteristics		
		Shape	Tip*	Glaze
Tanzania				
Uluguru	Ug 1	—	—	—
	Ug 2	—	—	—
	Ug 3	Slender	P	×
	Ug 4	Normal	R	○
	Ug 5	Slender	P	×
	Ug 6	Slender	S	×
	Ug 7	Normal	P	×
	Ug 8	Normal	S	×
	Ug 9	Normal	P	○
	Ug 10	Slender	P	×
	Ug 11	Slender	S	×
	Ug 12	Wide	R	○
North Tanzania	Nt 1	Normal	P	×
	Nt 2	Normal	R	○
	Nt 3	Normal	S	×
	Nt 4	Normal	R/P	×
	Nt 5	Normal	P	×
	Nt 6	Wide	P	×
	Nt 7	Slender	S/P	○
	Nt 8	Normal	S	○
	Nt 9	Normal	P	○
	Nt 10	Normal	S	○
	Nt 11	Normal	P	○
	Nt 12	Wide	P	○
	Nt 13	Normal	P	○
Java, Indonesia				
Bogor	Jw 1	Wide	S	○
Cianjur	Jw 2	Slender	P	×
Sumedang	Jw 3	Normal	P	○
	Jw 4	Slender	P	×
	Jw 5	Wide	S	×
Puruwokerto	Jw 6	Wide	P	×
	Jw 7	Slender	S	×
Magelang	Jw 8	Normal	P	○
Sleman	Jw 9	Wide	P	×
	Jw 10	Normal	P	○
Pakean	Jw 11	Wide	P	×
Indramayu	Jw 12	Slender	P	×

Source) Field survey by authors.
Note) * R: round, S: sharp, P: pointed.

Table 2. Jackfruit and related species used analysis as a comparison

Sample ID	Cultivar	Origin	Leaf characteristics		
			Shape	Tip*	Glaze
Artocarpus heterophyllus					
Is 1	Seedling	Indonesia	Normal	P	×
Is 2	Seedling	Indonesia	Normal	P	×
Ku 1	See Pan Chong	Thailand	Normal	S	○
Ku 2	Daen Suriya	Thailand	Normal	S	○
Ku 3	Pet Chim Lohng	Thailand	Wide	R	○
Ku 4	Ziman Pink	Hawaii	Slender	P	○
A. integer					
Ku 5	Liulianmi	Taiwan	Slender	P	×
A. heterophyllus × *A. integer*					
Ku 6	Chempedak	Taiwan	Slender	P	×

Source) Field survey by authors.
Note) * R: round, S: sharp, P: pointed.

2. DNA Extraction for Genetic Analysis

DNA was extracted from dry leaf samples by using a cetyltrimethylammonium bromide (CTAB) method (Doyle & Doyle, 1987). One or two leaves from each sample were placed in a plastic bag containing silica gel until completely dry. The leaves were then ground in liquid nitrogen by using a pestle and mortar. Powdered leaves (15 mg) were mixed with 200 μL 2× CTAB solution (2% CTAB, 0.1 M Tris-HCl [pH 8.0], 1.4 M NaCl, 20 mM ethylenediaminetetraacetic acid [EDTA]). The mixture was heated for 10 min at 65°C and then centrifuged for 3 min at 10,000 rpm. Supernatant (10 μL) was diluted by adding 90 μL TE 0.1 solution (10 mM Tris-HCl [pH 8.0], 0.1 mM EDTA). This solution was used as the DNA template for inter-simple sequence repeat (ISSR) analysis.

3. DNA Amplification

From ISSR primers UBC807 to 855 (University of British Columbia, Canada), nine primers per fruit species were selected and used to amplify DNA by polymerase chain reaction (PCR) method as described below. A 20 μL reaction solution containing 10 μL 2× Ampdirect Plus (Shimadzu Co., Ltd., Japan), 1 μL ISSR primer, 0.1 μL Biotaq™ (Nippon Genetics Co., Ltd., Japan), 1 μL DNA template, and 7.9 μL DDW (distilled deionized water) was prepared for one sample. The Ampdirect Plus buffer enabled reliable DNA amplification in the presence of impurities. The reaction solution was subjected to the PCR in a thermal cycler (Gene Atlas, Astec Co., Ltd., Japan) at 95°C for 10 min, followed by 40 cycles of 94°C for 30 s, 55°C for 1 min, and 72°C for 1 min (Table 7). The solution was then incubated at 72°C for 7 min, and kept at 4°C. Amplified solutions were electrophoresed at 1.7% agarose gel. This procedure was repeated at least twice to confirm the ISSR results.

Table 3. Mango accessions from Tanzania and Java

Location	Sample ID	Local name
Tanzania		
Uluguru	Tz 1	Dodo
	Tz 2	Bongwa
	Tz 3	Dodo
	Tz 4	—
	Tz 5	—
North Tanzania	Tz 6	Mviringo
	Tz 7	Dodo
	Tz 8	Sikio Punda
Java, Indonesia		
Bogor	Jw 1	Apel
	Jw 2	Indramayu
	Jw 3	Golek
Sumedang	Jw 4	Harumanis
	Jw 5	Cibur
	Jw 6	Manalagi
Purwokerto	Jw 7	(Seedling)
	Jw 8	(Seedling)
	Jw 9	(Seedling)
Magelang	Jw 10	(Seedling)
	Jw 11	(Seedling)
Sleman	Jw 12	Harumanis
Limpung	Jw 13	Gayung
Indramayu	Jw 14	Indramayu
	Jw 15	Manalagi
	Jw 16	Gedong Gincu
	Jw 17	Harumanis
	Jw 18	Gedong
	Jw 19	Cengkir (Indramayu)
	Jw 20	Gajah
	Jw 21	Indramayu

Source) Field survey by authors.

4. Data Analysis

Clear genetic polymorphisms were recorded from the resulting band patterns obtained from the ISSR analysis. According to the presence or absence of clear band, 1 or 0 data matrix was made. The 'poppr' package (Kamvar et al., 2014; Kamvar et al., 2015) in R software (R Development Core Team, 2005) was used to calculate Nei's genetic distance (Nei, 1972), and a dendrogram was generated by using the unweighted pair group method with arithmetic mean, UPGMA.

Table 4. Tested accession of mango and related species to make comparison

Sample ID	Cultivar	Origin
Mangifera indica		
Ku 1	Alampur Benashan	Florida (India)
Ku 2	Bennet Alphonso	Florida (India)
Ku 3	Irwin	Florida
Ku 4	Keitt	Florida
Ku 5	Neelam	India, Pakistan
Ku 6	(Seedling)	Taiwan
M. pentandra		
Ku 7	—	Thailand
Ku 8	—	Thailand
Ku 9	—	Thailand

Source) Field survey by authors.

Shannon's information index (I) and Nei's genetic diversity index (He) were calculated based on the genetic distance data matrix by using GenAlEx 6.5 (Peakall & Smouse, 2012, 2006), and a principal coordinate analysis (PCoA) was conducted.

RESULTS

I. Similarity of Homegardens between East Africa and Southeast Asia

1. Homegarden Configuration and Allocation of Component Species

Jalala homegardens surveyed in the Uluguru Mountains are round or irregularly shaped. Some are surrounded by crop fields, and others are next to other *jalala*. The house is generally located at the center of the *jalala* and is always adjacent to an open space (Fig. 2). Mango, breadfruit, and jackfruit plants are often cultivated in *jalala* but are scattered, and the numbers of these trees per *jalala* are small. In contrast, banana plants were densely planted in every *jalala*. Some *jalala* had a plot for intensive cultivation of banana, which implies commercial production (Photo 5). Spice crops such as cinnamon and clove trees, and pepper and vanilla vines were often densely planted in some areas in *jalala*. Many *jalala* included small areas for cultivation of vegetables and field crops for home consumption. Taro, maize, cassava, and other crops are grown in *jalala*. Field crop areas were sometimes located near the borders of the *jalala*. Vegetables such as tomato and African eggplant were cultivated around the open space adjacent to the house. It was like a kitchen garden. Vetiver grass was occasionally cultivated along the footpath or border of the *jalala*. This grass is used to make roofs and to protect against erosion.

Pekarangan are generally square, with the house located at the center (Fig. 3), and many *pekarangan* had fish ponds. Goat and poultry were more frequently

Table 5. Banana accessions obtained from Tanzania

Location	Sample ID	Local name
Uluguru	Ug 1	Mshale from Arusha
	Ug 2	Mshale
	Ug 3	Mtwike
	Ug 4	Mtwike
	Ug 5	Mtwike
	Ug 6	Bukoba
	Ug 7	Mtwike
	Ug 8	Mtwike
	Ug 9	Mtwike
	Ug 10	Mzungu mwekundu
	Ug 11	Mshale
	Ug 12	Mzuzu
North Tanzania	Nt 1	Malindi
	Nt 2	Jamaica
	Nt 3	Mkojozi
	Nt 4	Mshale
	Nt 5	Kisukari tamu
	Nt 6	Jamaica
	Nt 7	Mshale
	Nt 8	Mtoni
	Nt 9	Uganda
	Nt 10	Kisukari
	Nt 11	Ndizi ng'ombe
	Nt 12	Mbwe
	Nt 13	Mshale
	Nt 14	Uganda
	Nt 15	Uganda fupi
	Nt 16	Kibungara
	Nt 17	Uganda bukoba
	Nt 18	Uganda bukoba
	Nt 19	Kisukari izraeli
	Nt 20	Mkono wa tembo
	Nt 21	Jamaica
	Nt 22	Mgomba pori
	Nt 23	Kibungara
	Nt 24	Jamaica
	Nt 25	Kiazi
	Nt 26	Mshale
	Nt 27	Pazi
	Nt 28	Chinese
	Nt 29	Kisukari
	Nt 30	Uganda nyeupe
	Nt 31	Mkojozi
	Nt 32	Uganda nyekundu
	Nt 33	Malindi

Source) Field survey by authors.

Table 6. Banana accessions from Java

Sample ID	Local name	Origin
Jw 1	Tanduk	Java
Jw 2	Ambon rumut	Java
Jw 3	Kepok	Java
Jw 4	Nangka	Java
Jw 5	Ambon	Java
Jw 6	Uli	Java
Jw 7	Mas	Java
Jw 8	Cavendish	Java
Jw 9	Raja bulu	Java
Jw 10	Mas kirana	Java
Jw 11	Barangan	Java
Jw 12	Tanjung	Sulawesi
Jw 13	Lokabule	Sulawesi
Jw 14	Untisayang	Sulawesi

Source) Field survey by authors.

Table 7. ISSR primers used for genetic analysis and annealing temperatures

UBC Primer*	Sequence	Annealing temperature (°C)		
		Mango	Jackfruit	Banana
807	(AG)8T	52	55	
808	(AG)8C	52	55	
810	(GA)8T		52	
811	(CT)8T	52		55
813	(CA)8T			53
816	(CA)8T		52	
818	(CA)8G	52	52	53
825	(AC)8T	52		
826	(AC)8C	55		55
827	(AC)8G		55	
834	(AC)8YT		55	53
835	(AG)8YC		52	55
836	(AG)8YA	54		55
840	(GA)8YT	52		55
841	(GA)8YC			55
842	(GA)8YG		55	
855	(AC)8YT	53		

Source) * University of British Columbia in Canada.

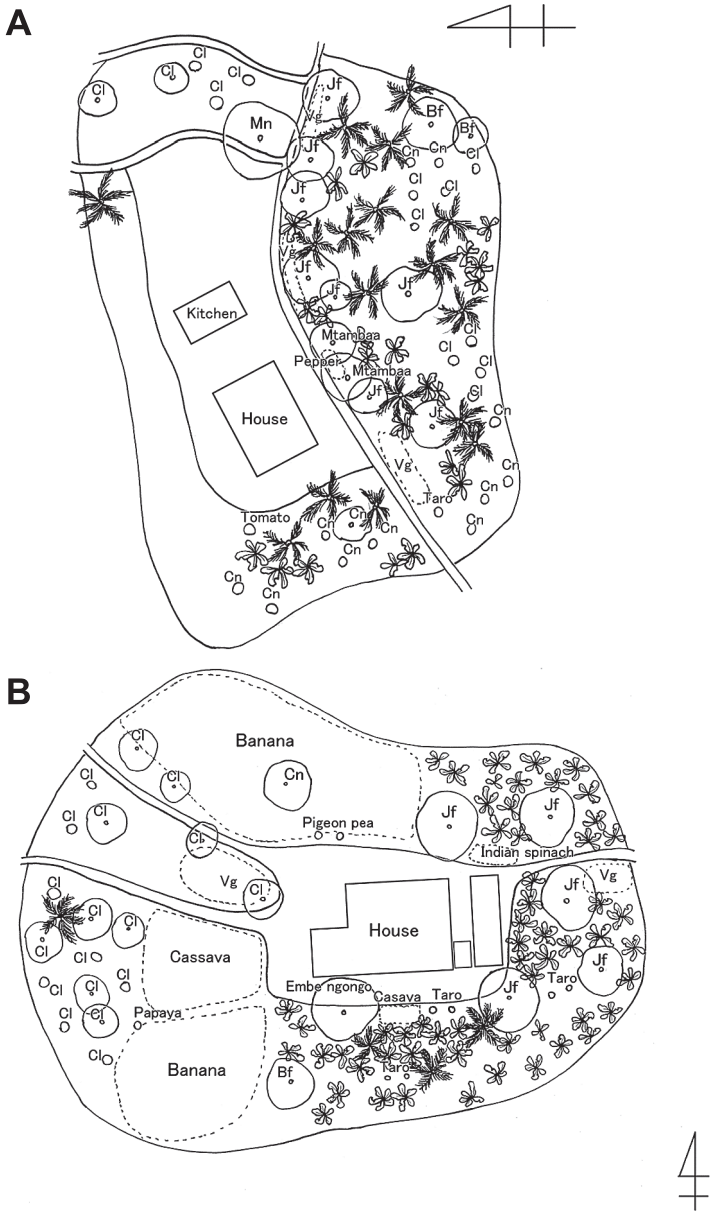

Fig. 2. Airscape of Uluguru Homegardens (*jalala*), and cross section of typical *jalala*
Source) Field Survey by authors in 2016.
Note) A) Coco palms and tall tree crops like mango and jackfruit are planted. Clove and cinnamon cultivation is intensive.
B) Intensive banana cultivation is conducted.
C) Typical *jalala* with tall tree crops and intensive banana cultivation.
D) Cross section of C) *jalala* between A-B line.

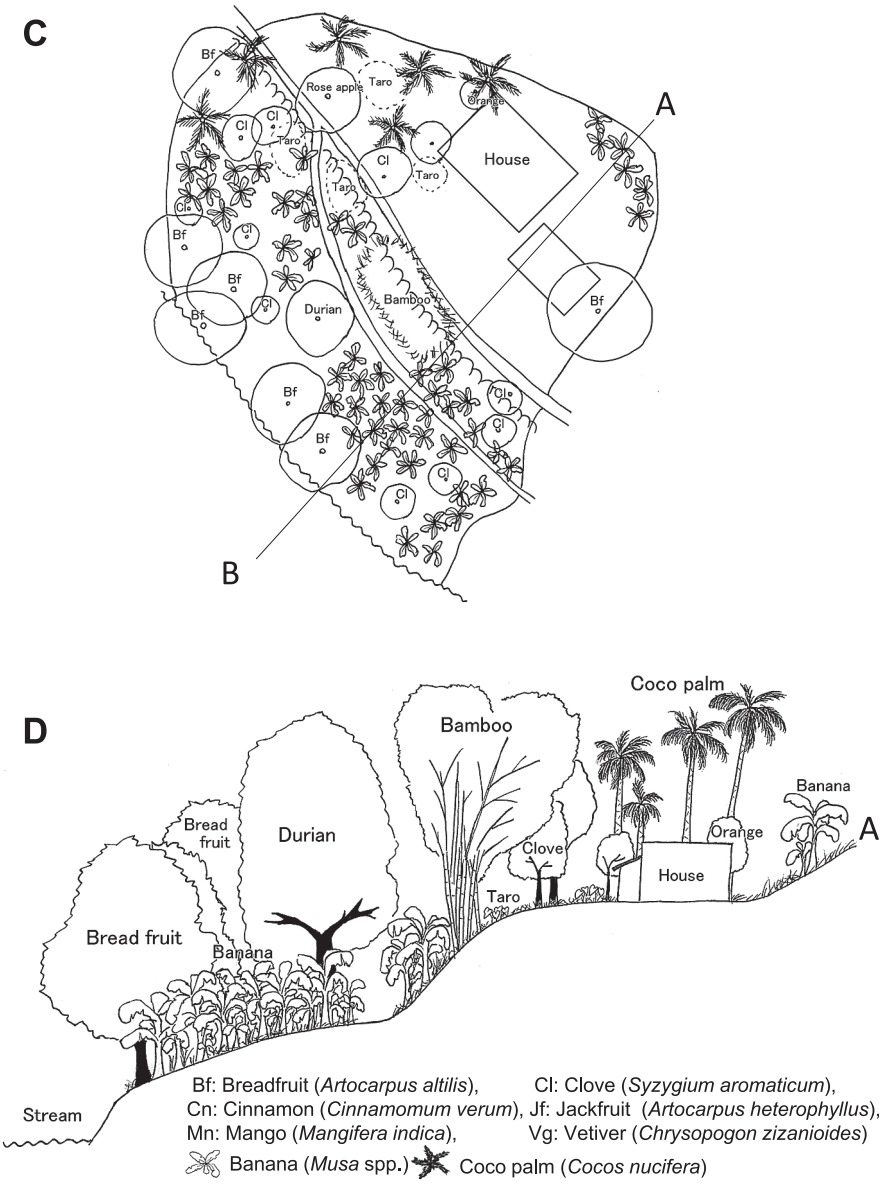

Fig. 2. (continued)

raised in *pekarangan* than in *jalala*. Many trees were found growing in dispersed patterns. Fruit trees were popular and many species were cultivated, although the number of each species were small. Banana was planted in many *pekarangan*, albeit less intensively than in *jalala*. *Pekarangan* lacked dense banana plots. Other than banana, jackfruit and mango trees were often planted in *pekarangan*. Although these trees naturally grow to considerable heights, relatively small young jackfruit

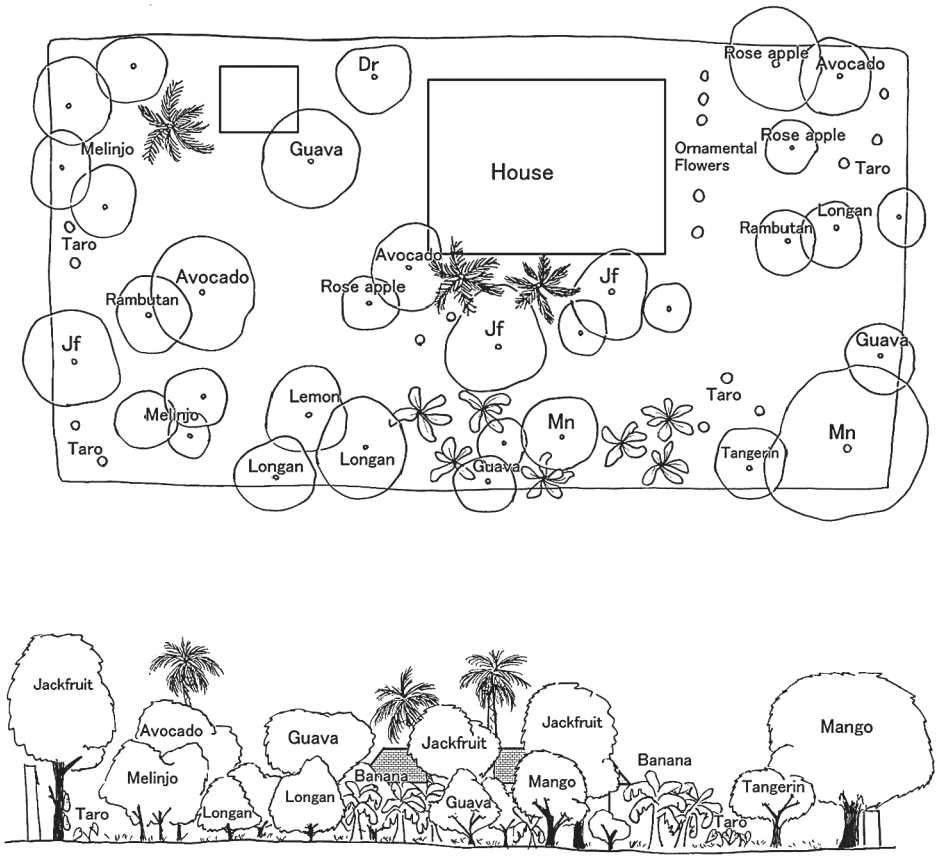

Fig. 3. Airscape of typical Java Homegarden (*pekarangan*) and cross section
Source) Field Survey by authors in 2014.
Note) *Pekarangan* is often square and smaller than *jalala*. Trees are shorter but many species are planted.

and mango trees were frequently found in *pekarangan*. Jackfruit timber is popular and expensive. If a household needs wood, jackfruit trees are cut without hesitation, because most are planted rather for the purpose of timber. Large mango trees were seldom found, possibly because most modern commercial cultivars are dwarf trees, although many old and large mango trees were found in the Uluguru Mountains.

The numbers and diversities of vegetable and field crops in *pekarangan* were lower than in *jalala*, although those crops were cultivated under the canopies of woody plants. Field crop plots, if present, were usually located in the back yard or along the border of *pekarangan*. Ornamental plants, which were seldom observed

in *jalala*, were popular in *pekarangan*. they were usually arranged in the front yard, around the porch of the house, or near the entrance of the *pekarangan*. *Pekarangan* were smaller but contained a larger number of plant species compared with *jalala*. In terms of functional land use, most *jalala* were similar to orchards or crop fields, while *pekarangan* were similar to landscape gardens, likely a result of urbanization, as discussed by Arifin et al. (1997).

2. Species in Homegardens

The average area of *jalala* in the Uluguru Mountains was 0.27 ha and that of *pekarangan* in Java was 0.07 ha (Table 8). The average number of crop species per household in *jalala* was 11.8 and 18.8 in *pekarangan*; these figures exclude ornamental species, which were plentiful in *pekarangan*. A greater number of plant species were cultivated more intensively in *pekarangan* than in *jalala*.

Fruit crops were cultivated more frequently than spice crops, vegetable and field crops, timber wood, and other crops in both types of homegarden (Table 8). In Java, the average number of fruit crops was 11.0, more than half of the total number of species. The *H'* of homegarden species was 1.95 in the Uluguru Mountains and 2.99 in Java. This is slightly in contrast with the impression given by the external appearance of the homegardens. Uluguru homegardens have many tall, old trees, which compensate for plant spacing and form a thick, multi-layered landscape similar to a natural tropical forest.

In total, 37 crops were found in Uluguru homegardens (Table 9). Fruit crops (e.g., banana and jackfruit), field crops (e.g., taro and cassava), and spice crops (e.g., cinnamon and clove) were observed frequently. Of these crops, 5 originated in Africa and 18 in tropical Asia. In total, 39 crops were found in Java homegardens, excluding ornamental plants. Fruit crops were observed most frequently, some of which are native to tropical Asia and were not observed in Uluguru. Twenty-one common species were found in both the Uluguru Mountains and Java, of which 13 species were fruit crops. Banana, jackfruit, mango, and coco palm were the predominant plant species in both locations.

Table 8. Homegardens in Uluguru and Java: size and component species with diversity index (*H'*)

	Number of households	Area (ha)	Number of species						Diversity index (*H'*)*
			Fruit crops	Field crops	Spice crops	Timber trees	Others	Total	
Uluguru	18	0.28 a	5.2	3.6	2.1	0.8	0.1	11.8 b	1.95 b
Java	8	0.07 b	11	2.8	0.8	3.1	1.1	18.8 a	2.99 a

Source) Analysis by authors.
Note) Different letters indicate significant differences at $P < 0.05$.
*Shannon–Wiener index (Shannon, 1948).

Table 9. Crop species observed in Uluguru and Java homegardens

English name	Scientific name	Local names		Households	
		Swahili	Indonesia	Uluguru	Java
Fruit crops					
Banana	*Musa* spp.	Mgomba	Pisang	8	7
Jackfruit	*Artocarpus heterophyllus*	Mfenesi	Nangka	6	7
Coco palm	*Cocos nucifera*	Mnazi	Kelapa	6	4
Mango	*Mangifera indica*	Mwembe	Mangga	4	6
Papaya	*Carcia papaya*	Mpapai	Pepaya	2	6
Wax apple	*Syzygium* spp.	Mtofaa	Jambu air	2	5
Breadfruit	*Artocarpus altilis*	Msherisheri	Sukun	5	1
Rambutan	*Nephelium lappaceum*	Mshokishoki	Rambutan	1	7
Orange	*Citrus sinensis*	Mchungwa	Jeruk manis	2	1
Avocado	*Persea americana*	Mparachichi	Alpukat	2	4
Sour sop	*Annona muricata*	Mstafeli	Sirsak	1	5
Guava	*Psidium guajava*	Mpera	Jambu biji	1	5
Ambarella	*Spondias dulcis*	Mwembe ng'ongo	—	3	
Bilimbi	*Averrhoa bilimbi*	Mbilimbi	Belimbing asam		1
Lemon	*Citrus limon*	Mlimau	Limun		1
Durian	*Durio zibethinus*	Mduriani	Durian		3
Sweet sop	*Annona squamosa*	Mtopetope	Srikaya		1
Coffee	*Coffea* spp.	Mbuni	—	5	
Passion fruit	*Passiflora* spp.	Mpassioni	—	3	
Gnemon	*Gnetum gnemon*	—	Melinjo		6
Twisted cluster bean	*Parkia speciosa*	—	Pete		4
Longan	*Dimocarpus longan*	—	Longan		3
Pineapple	*Ananas comosus*	Mnanasi	Nanas	2	1
Wild mango	*Mangifera foetida*	—	Pakel		2
Mangosteen	*Garcinia mangostana*	—	Manggis		2
Vegetables/Field crops					
Taro	*Colocasia*, *Xanthosoma*	Myugwa	Talas	5	3
Cassava	*Manihot esculenta*	Mhogo	Singkong	3	5
Red pepper	*Capsicum* spp.	Pilipili	Lombok/Cabai	3	3
African eggplant	*Solanum nigrum*	Nyanya chungu	Leunca	1	2
Squash	*Cucurbita* spp.	Boga	Waluh	1	1
Sweet potato	*Ipomoea* spp.	Kiazi kitamu	Ubi manis/Ubi jalar	1	1
Tomato	*Lycopersicon esculentum*	Nyanya	—	2	
Amaranth	*Amaranthus* spp.	Mchicha	—	1	
Malabar spinach	*Basella alba*	Derege	—	5	
Sugar cane	*Saccharum officinarum*	Mwa	—	2	
Vetiver grass	*Vetiveria zizanioides*	Kashikashi	—	2	
Rice	*Oryza* spp.	Mpunga	—	1	

Table 9. (continued)

English name	Scientific name	Local names		Households	
		Swahili	Indonesia	Uluguru	Java
Common bean	*Phaseolus vulgaris*	Mharagwe	—	1	
Lablab bean	*Lablab purpurea*	Mfiwi	—	1	
Okra	*Abelmoschus esculentus*	Mbamia	—	1	
Egg plant	*Solanum melongena*	Mbilingani	Terong		1
Spinach	*Spinacia oleracea*	Spinachi	Bayam		1
Star gooseberry	*Sauropus androgynus*	—	Katuk		1
Spice crops					
Clove	*Syzgium aromaticum*	Mkarafuu	Cengkeh	6	1
Cinnamon	*Cinnamomum verum*	Mdalasini	—	7	
Vanilla	*Vanilla planifolia*	Vanila	—	5	
Pepper	*Piper nigrum*	Pilipili manga	—	3	
Cardamom	*Elettaria cardamomum*	Iliki	—	1	
Lemon grass	*Cymbopogon citratus*	Mchaichai	Serai		3
Turmeric	*Curcuma longa*	Manjano/Bizari	Kunyit		1
Laurel	*Laurus nobilis*	—	Salam		1
Timber trees					
Chinaberry	*Melia* spp.	—	—	3	3
Mahogany	*Swietenia* spp.	Mkangazi	Mahoni		5
Teak	*Tectona* spp.	Msaji	Jati		1
Kapok	*Ceiba pentandra*	Msufi	Kapuk		1

Source) Field survey by authors.

II. Plant Use and Genetic Similarity among Fruit Crops

1. Plant Use and Local Names

Jackfruit varied leaf morphology among accessions but not among locations (Tables 1 and 2). No jackfruit cultivars or variations were found in Tanzania nor Indonesia according to local recognition. In Tanzania, jackfruit is consumed mostly as table fruit. In Indonesia, jackfruit is used not only for table fruit but also in iced desserts; e.g., *es campur* and *es cendol*. Young jackfruit is cooked to make *gudeg*, a sweet and salty local dish, or a sauce called *sambal*. Jackfruit seeds are frequently consumed as a snack.

Most mango trees had local variety names (Table 3), but some older trees had no name. The names of the major varieties differed among the study areas. In Tanzania, '*Dodo*', a large fruit variety, is popular and planted in both the Uluguru and Northern Mountains. '*Bongwa*', a large tree that produces small fruit, is frequently found along the street. The '*Mviringo*' tree produces round, medium-sized fruit and is frequently planted in the Northern Mountains. In Tanzania, mango is used only as a table fruit. The most popular mango cultivars in Java are

'*Harumanis*', followed by '*Manalagi*'. '*Indramayu*' is also popular. These cultivars are available in many markets in Java. '*Indramayu*' is the name of a city on the north coast of West Java. The mango cultivar '*cengkir*', produced in Indramayu, is known as '*Indramayu*' in other regions. The above three varieties are sweet mangoes and are used mainly as table fruit. The variety '*Cibur*' (Table 3) is used to make *rujak* (fruit salad) and is generally pickled. Indramayu city is famous for its mango production, and traders travel there to purchase surplus mango. Surplus mangoes are also used to make *dodol*, a type of toffee. The '*Gajah*' variety is seedless, meaning that it has an empty kernel.

Banana in Tanzania had many local names (Table 5); its uses and genotypic classifications are listed in Table 10. Morphological classification was conducted

Table 10. Names, usages, and genotypes of local banana varieties and ensete from Tanzania

Local name	Location		Usage	Genotype
	Uluguru	North Tanzania		
Bukoba	1		Cooking	AAA
Chinese		1	Fresh	—
Jamaica		4	Fresh, Cooking	AAA
Kiazi		1	Cooking	—
Kibungara		3	Beer brewing	—
Kisukari		2	Fresh	ABB
Kisukari tamu		1	Fresh	ABB
Kisukari izuraeri		1	Fresh	ABB
Malindi		2	Fresh	AAA
Mkojozi		2	Cooking	ABB
Mkono wa tembo		1	Cooking	AAB
Mshale (Uluguru)	3		Fresh, Cooking	AA
Mshale (North-Tnz)		4	Fresh	AA
Mtoni		1	Cooking	—
Mtwike	6		Fresh, Cooking	AAA
Mzungu mwekundu	1		Fresh	AAA
Mzuzu	1		Cooking	AAB
Ndizi ng'ombe		1	Cooking	—
Pari		1	Fresh	AAA
Uganda		2	Cooking	AAA
Uganda nyeupe		1	Fresh	AAA
Uganda nyekundu		1	Fresh	AAA
Uganda bukoba		2	Cooking	AAA
Uganda fupi		1	Cooking	AAA
Mgomba pori		1	Ornamental	—

Source) Field survey by authors.
Note) Genotype was determined according to criteria from Simmonds (1966); Evers (1992); Komatsu et al. (2006); Ploetz et al. (2007); Karamura et al. (2012).

by using information from Simmonds (1966); Evers (1992); Komatsu et al. (2006); Ploetz et al. (2007); and Karamura et al. (2012). The cultivar '*Mtuike*' is predominant in the Uluguru Mountains, which reportedly had many banana cultivars (e.g., Komatsu et al., 2006); however, the number of cultivars has decreased recently as a result of disease. '*Mtuike*' appears to be a highly disease-tolerant cultivar. According to circumstantial situation, this disease might be New Panama Disease; The disease threat expanded to the east coast of Tanzania in 2012 (Ploetz, 2015). Most banana cultivars in the Uluguru Mountains are consumed fresh when ripe or used as cooking bananas if harvested sooner. In contrast, the many banana cultivars planted in the Northern Mountains are used in various ways. '*Uganda*' is cooked in a stew, '*Mkojozi*' is mashed to make a salad, and '*Kibungara*' is used to produce a local alcoholic beverage.

In Indonesia, 11 accessions of banana are native to Java, and 3 are from the island of Sulawesi (Table 6). The morphological traits of these accessions varied markedly. Their uses and genotypic classification are listed in Table 11. All of the Java banana cultivars are used as table fruit. Inflorescences of some cultivars are boiled for use as vegetables. '*Ambon*' is the most popular cultivar used for table fruit. Irrespective of the cultivar, immature fruits are used in *rujak* (fruit salad), fried to make *pisang goreng* (a snack), or grilled to make *pisang bakar* (a dessert). The cultivars '*Tanduk*' and '*Uli*' are consumed as a snack known as *kolak*, which is a mixture of coconut milk, sugar, and mature sweet banana. Banana is not regarded as a staple food in Indonesia.

Table 11. Names, usages, and genotypes of local banana varieties from Indonesia

Local name	Usage	Genotype
Java accessions		
Ambon	Fresh	AAA
Ambon lumut	Fresh	AAA
Barangan	Fresh	AAA/AA
Cavendish	Fresh	AAA
Kepok	Cooking, Fresh	ABB/BBB
Mas	Fresh	AA
Mas kirana	Fresh	AA
Nangka	Fresh, Cooking	AAA/AAB
Raja Bulu	Fresh, Cooking	AAB
Tanduk	Fresh, Cooking	AAB
Uli	Fresh, Cooking	AAB
Sulawesi accessions		
Loka bule	Cooking	ABB/BBB
Tanjung	Cooking	ABB/BBB
Unti sayang	Cooking	ABB/BBB

Source) Field survey by authors.
Note) Genotype was according to Simmonds (1966); Evers (1992); Komatsu et al. (2006); Ploetz et al. (2007); Karamura et al. (2012).

2. Genetic Distances

(1) Jackfruit

In total, 45 accessions of jackfruit were analyzed by using nine ISSR primers, and 91 polymorphic band patterns were detected (Table 12). The largest and small-

Table 12. ISSR primer and polymorphic bands

UBC Primer	Number of polymorphic bands	Number of total bands	Percentage of polumorphic bands
Jackfruit			
807	9	9	100
808	11	11	100
810	9	10	90
816	9	10	90
818	8	9	89
827	8	11	73
834	13	13	100
835	11	11	100
842	13	15	87
Total	91	99	92
Mango			
807	12	13	92
808	10	10	100
811	11	12	92
818	8	8	100
825	6	6	100
826	9	9	100
836	11	11	100
840	12	12	100
855	13	13	100
Total	92	94	98
Banana			
811	17	17	100
813	8	9	89
818	8	8	100
826	10	11	91
834	11	11	100
835	12	12	100
836	12	12	100
840	13	13	100
841	13	13	100
Total	104	106	98

Source) Analysis by authors.

est genetic distances were 0.518 and 0.095, respectively. Genetic diversity was the highest in the Northern Mountains of Tanzania (Table 13).

Cluster analysis indicated that the jackfruit samples comprised three genetic categories (Fig. 4). Cluster I included only Ku 5 and cempedak (*A. integer*). Cluster II included three accessions from the Northern Mountains. All other accessions were included in cluster III. Accessions from the Uluguru Mountains were found to be closely related, and some were also related to accessions from the Northern Mountains. Java accessions were similar to commercial cultivars.

According to PCoA, the first principal component showed separation of Tanzanian accessions from Java accessions and from the commercial cultivars (Fig. 5).

Table 13. Genetic distance and indexes of diversity of jackfruit, mango, and banana

Fruit tree	Location	Number of samples	Genetic distance [z] (max–min)	*I* [y]	*He* [x]
Jackfruit	Uluguru	12	0.305–0.095	0.356 b	0.241 b
	North Tanz	13	0.470–0.187	0.423 a	0.286 a
	Java	12	0.341–0.154	0.343 b	0.232 b
Mango	Tanzania	8	0.591–0.154	0.369 b	0.245 b
	Java	21	0.852–0.171	0.445 a	0.300 a
Banana	Uluguru	12	0.524–0.125	0.330 b	0.218 b
	North Tanz	33	0.772–0.085	0.484 a	0.320 a
	Java	14	0.540–0.077	0.461 a	0.312 a

Source) Analysis by authors.
Note) [z]: Nei's genetic distance (Nei, 1972). [y]: Shannon information index. [x]: Average expected heterozygosity (Nei's genetic diversity).

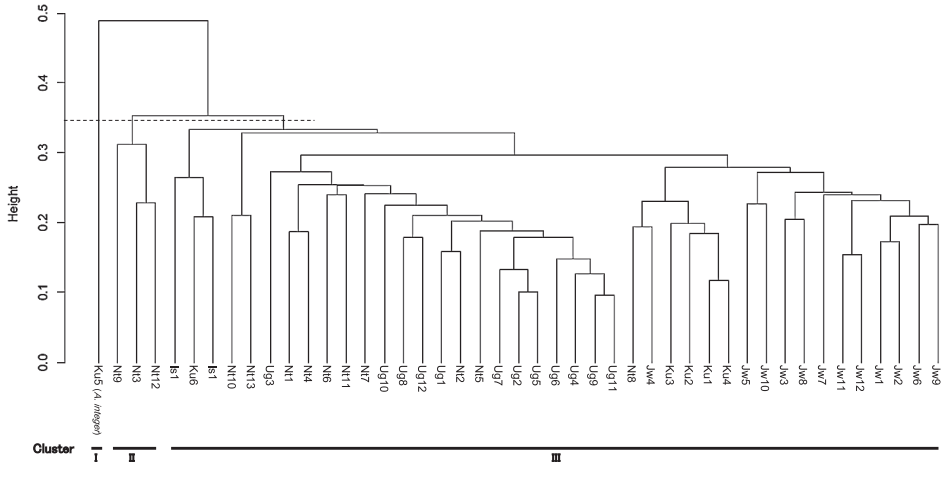

Fig. 4. Dendrogram obtained by UPGMA indicating genetic distance of jackfruit by ISSR analysis
Source) Analysis by authors.
Note) The genetic distances were calculated according to Nei (1972).

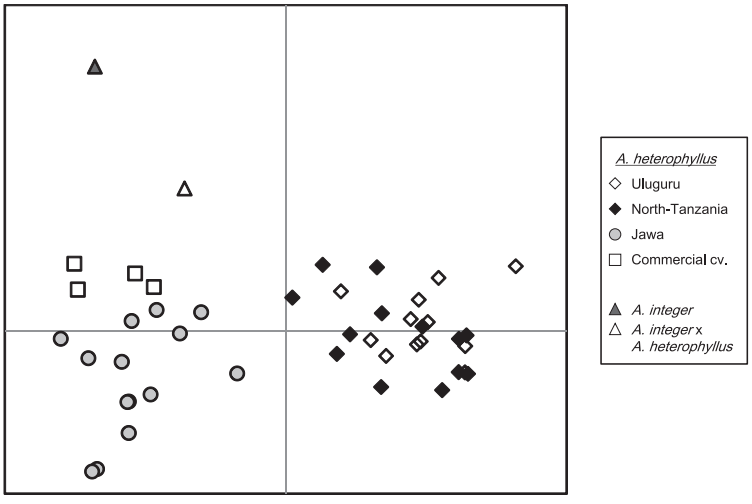

Fig. 5. PCoA result of jackfruit gene by ISSR
Source) Analysis by authors.
Note) The genetic distances were calculated according to Nei (1972).

Tanzanian accessions formed one group irrespective of their sampled location. Cempedak and Ku 5 were positioned at positive location on the second principal component. Ku 6, a hybrid cultivar of cempedak and jackfruit, was positioned between cempedak and jackfruit in the PCoA, reflecting the genetic background accurately.

(2) Mango

In total, 38 mango accessions were analyzed by using nine ISSR primers, and 92 polymorphic band patterns were detected (Table 12). The largest and smallest genetic distances were 0.862 and 0.154, respectively. Genetic diversity was significantly higher in Java than in Tanzania (Table 13).

Cluster analysis of these accessions resulted in identification of five clusters (Fig. 6). Cluster I contained three accessions of *M. pentandra*. Cluster II contained only 'Apel' cultivar. Cluster III contained all of eight Tanzanian accessions. In this cluster, genetically different types of '*Dodo*' were included. Cluster IV included the commercial cultivars Ku 1–Ku 6. Cluster V consisted of Java accessions, although the seedless cultivar '*Gajah*' is different from the other Java varieties. '*Harumanis*' accessions indicated that they had various genetic background, as well as '*Dodo*' accessions.

The first principal component of the PCoA indicated separation of a group of Tanzanian and Indonesian accessions from the commercial cultivars evaluated (Fig. 7), and the Tanzanian accessions were closer to the Indonesian accessions than to the commercial cultivars. The wild mango *M. pentandra* was genetically distant from *M. indica* mango accessions.

(3) Banana

In total, 59 accessions of banana were analyzed by using nine ISSR primers, and 104 polymorphic band patterns were detected (Table 12). The largest and

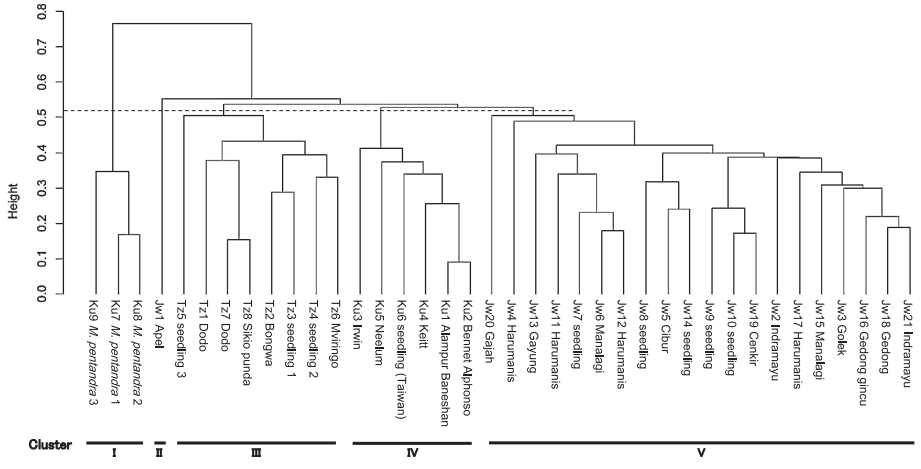

Fig. 6. Dendrogram obtained by UPGMA indicating genetic distance of mango by ISSR analysis
Source) Analysis by authors.
Note) The genetic distances were calculated according to Nei (1972).

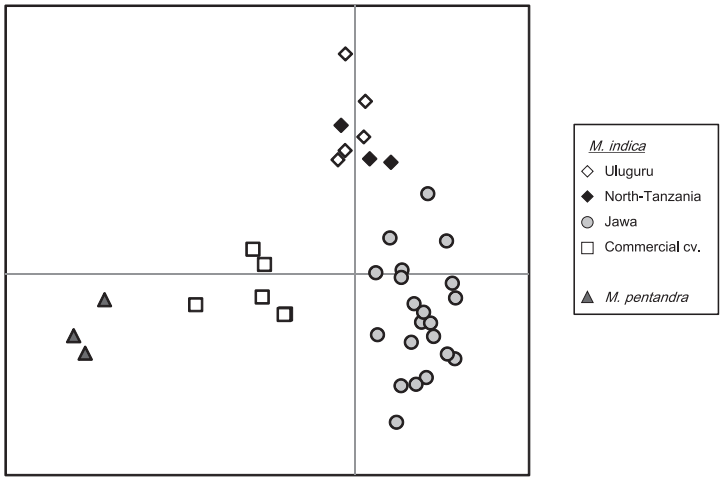

Fig. 7. PCoA result of mango gene by ISSR
Source) Analysis by authors.
Note) The genetic distances were calculated according to Nei (1972).

smallest genetic distances were 1.014 and 0.076, respectively. Genetic diversity was significantly lower in the Uluguru Mountains. There were no significant differences between the Northern Mountains and Java accessions (Table 13).

The banana accessions were divided into three clusters by cluster analysis. Cluster I contained Nt22, *mgomba pori*, an ornamentally planted wild ensete (Fig. 8). Cluster II contained 53 accessions, which were divided into 5 categories i, ii, iii, iv, and v. Cluster II-i contained Ug12, '*Mzuzu*' (genotype AAB), and Ut10, '*Kisukari*' (genotype ABB). Cluster II-ii contained '*Mtuike*' (genotype AAA)

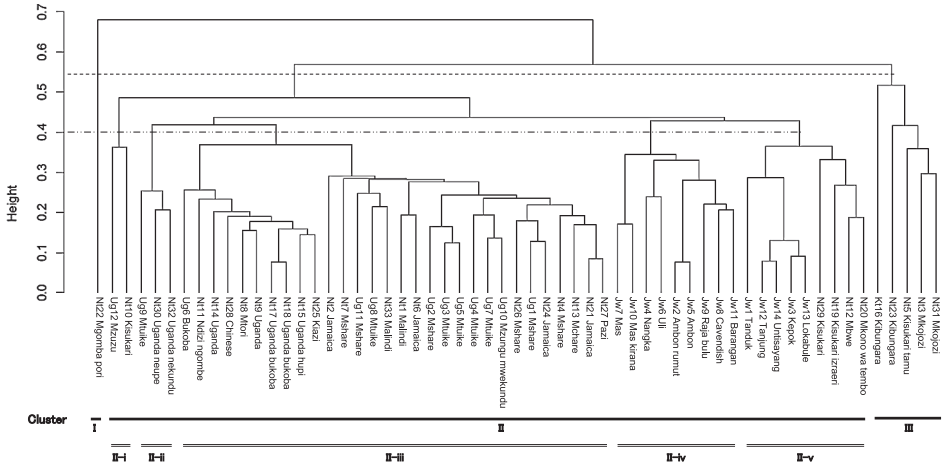

Fig. 8. Dendrogram obtained by UPGMA indicating genetic distance of banana by ISSR analysis
Source) Analysis by authors.
Note) The genetic distances were calculated according to Nei (1972).

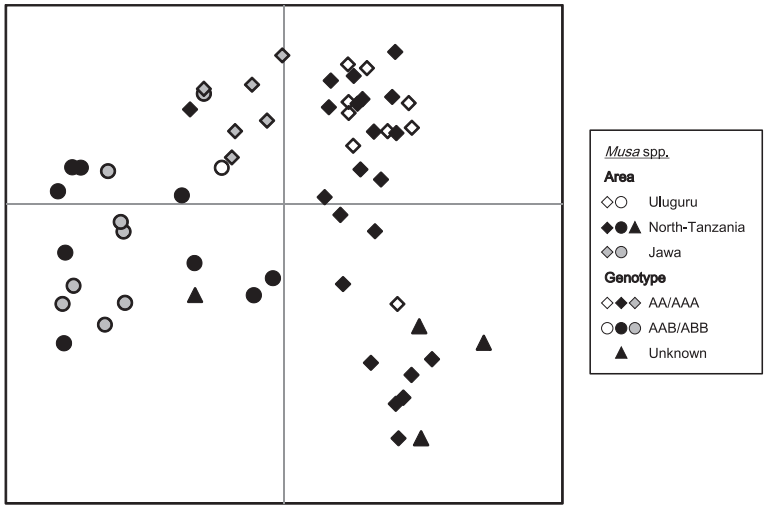

Fig. 9. PCoA result of banana gene by ISSR
Source) Analysis by authors.
Note) The genetic distances were calculated according to Nei (1972).

from the Uluguru Mountains and Uganda (genotype AAA) from the Northern Mountains. Cluster II-iii contained 30 accessions, and all of them were genotype AAA. Cluster II-iv contained nine Java accessions of genotypes AAA and AAB. Cluster II-v contained five accessions from Java and four accessions from the Northern Mountains, which were of the AAB and ABB genotypes. Cluster III contained five accessions, including cultivars '*Kisukari*' and '*Mkojozi*' (genotype ABB), and brewing cultivar '*Kibungara*'.

PCoA indicated a wide distribution without making clear groups (Fig. 9). The first principal component divided the genotypes into two groups: AAA and AAB/ABB. The second principal component separated cooking bananas from the AAA genotype accessions. Banana varieties used as table fruit or as both table and cooking fruit made single group at negative direction of the second principal component. Most Uluguru Mountain accessions were classified into this group. AAB/ABB genotype accessions showed a sparse distribution. Northern Mountains accessions also showed a wide distribution. Indonesian accessions formed a smaller group, and they were divided into two groups of AAA and AAB/ABB.

DISCUSSION

I. Homegarden Species and Plant Use in the Uluguru Mountains

Banana was cultivated in all 18 homegardens surveyed in the Uluguru Mountains. Cinnamon was also cultivated at a high frequency. Tree species, including banana and cinnamon, are important cash crops and characterized Uluguru homegardens. In the Uluguru Mountains, food production from crop fields is insufficient because of climatic instability and low soil fertility (Higuchi et al., 2011). Production of marketable fruits and spices in homegardens can compensate for an insufficient crop field harvests.

The most important cash crop is banana, which is mainly grown for sale, although it is also consumed by the local population. Other fruit crops are seldom sold outside of the Uluguru Mountains, because the road network is insufficient and the conditions are unsuitable for the transport of heavy and perishable fruits. The second important cash crop is spice (e.g., cinnamon). The Luguru people in the study site are Muslim and are familiar with spices. The environment in the Uluguru Mountains is suitable for growing several spice species, and so cultivation of spices has increased. This is possibly due to connections with the Luguru community in Zanzibar. According to Luguru elders, approximately 50–60 years ago, this community introduced many tropical fruit trees and spice crops to the Uluguru Mountains.

Among the spice crops, cinnamon is relatively tolerant to drought and low temperatures and is currently the most important spice crop in the Uluguru Mountains. The tree requires at least 5–7 years to grow to an appropriate size to be harvested. However, it can be harvested anytime without season after the tree grows up to be a sufficiently large size. This no-season trait implies that it is a valuable stock for the Luguru, who don't keep large livestock. Cinnamon trees in homegardens can be valuable sources of revenue for the Luguru. Java homegardens frequently have fishponds and animals. However, raising livestock and maintaining fish ponds are difficult in Uluguru homegardens because they are located on slopes; thus, cinnamon is planted instead. Clove, pepper, cardamom, and vanilla are also raised as cash crops, although the production of these spices is not so large.

The low diversity (H') was observed for Tanzanian homegardens than Indonesia.

This is composed mainly of introduced exotic plants, implies a limited range of cash crops. Banana and some spice crops are intensively cultivated as cash crops, whereas other fruits and spices are cultivated rarely, resulting in low species diversity.

II. Establishment of Asian-style Homegardens in the Uluguru Mountains

Several factors are related to the unique homegardens with wet tropical landscape in the Uluguru Mountains. The existence of some species common to Asia and Africa can be explained by their introduction via trans-Indian Ocean trade routes and transport from coastal to inland areas along caravan routes.

Well-developed multi-layered homegarden landscapes are not common in East Africa except for in the Uluguru Mountains, despite the presence of mountainous areas with abundant rainfall. Some homegarden systems in other mountains are relatively monotonous; e.g., the *kihamba* system around Mount Kilimanjaro usually comprises coffee and banana plants, sometimes with additional trees to provide shade for the coffee plants (Maruo, 2002). This simple structure is partly a result of the lower temperature at higher altitudes, as well as outstanding economical advantage of coffee and banana than other crops. High altitude causes enough rainfall which is suitable for tropical fruit trees but low temperature is not suitable. Precipitation on the lower slopes of Kilimanjaro is insufficient to support humid tropical fruit species, although temperature is enough. Thus the structure of Uluguru homegardens is unique and a result of the surrounding ecological environment, which is rare in east Tanzania.

Jalala in the Uluguru Mountains are characterized by many spice crops. Spice cultivation might be supported by the tendency of Muslims to use spices in their food. Thus, *jalala* in the Uluguru Mountains have been influenced not only by the introduction of tropical fruit and spice crops from regions around the Indian Ocean, but also by the cultural background of the people living there.

III. Genetic and Geographical Distance of Fruit Crops

Tropical fruit crops such as jackfruit, mango, and banana, which originated in Southeast Asia, were observed in both the Uluguru Mountains and Java. Most other crops planted in the Uluguru Mountains are native to tropical Asia. The dissemination route of these crops is considered to be via two patterns: the coastal route from Asia via Arabia to East Africa, and the ocean route from insular Asia to Madagascar directly across the Indian Ocean. To evaluate species similarity between the homegardens of Tanzania and Indonesia, genetic similarity of the above tree species was examined.

Jackfruit originated in India (Reddy et al., 2004), but its route of dissemination to Tanzania is unclear. Grafting and cutting of jackfruit is not easy, so cultivated trees are mostly seedlings. Thus the fruit quality varies well and commercial production is limited. Jackfruit is cultivated frequently in Tanzania but used only as a table fruit. People do not distinguish its varieties. In Java, on the other hand, jackfruit is used as confectionery and for cooking and timber. Jackfruit trees

appear to be valued more highly in Java. However, jackfruit does not have local variety names, despite the marked variations in the morphology and taste.

Genetic distance among the sampled places was generally small for jackfruit, and accessions from different areas were clustered together in the cluster analysis. However, PCoA indicated differences between Asian and African accessions. This inconsistency between high genetic similarity and classification into different genetic groups suggests that some of the varieties introduced from Asia were propagated and expanded in Tanzania. Jackfruit is usually propagated by seedlings; therefore, genetic distance reflects geographical distance. The Uluguru Mountains are steep, which hampers transportation of the fruit. This resulted in small genetic diversity among Uluguru accessions. However, some Uluguru accessions are genetically similar to Northern Mountains accessions, suggesting some degree of exchange. Java jackfruit accessions, although they were located near the origin of the plant, showed lower genetic diversity. This is likely the result of artificial selection of trees during the long history of plant use in Java. Jackfruit from different districts in Java reportedly taste different (Ito et al., 2013), which supports some degree of artificial selection.

The mango originated from India and Malaysia. Cultivation of mango in India began 4000 years ago. Polyembryonic and monoembryonic types of mango are known. Polyembryonic mango conserves gene. Vegetative propagation is available as well as seed propagation. Persian traders are thought to have brought mango from India to Tanzania before the 10th century (Hoshikawa, 1987). Generally, domestication of fruit trees tends to maximize fruit size and minimize tree size. However, some large mango trees in Tanzania produce very small mango fruits, suggesting limited artificial selection. Therefore, older varieties may be extant in Tanzania. Genetic categorization of the mango differed according to geography; Tanzanian mango accessions were found to be genetically close to those of Java rather than to the commercial cultivars evaluated. This may indicate that some old varieties were brought to Tanzania from Southeast Asia including Java. This is in contrast to the notion suggested by Hoshikawa (1987) that they arrived via India.

Cultivated banana is usually a hybrid of *M. acuminata* and *M. balbisiana* or a polyploid of either species. Generally, banana fruit has no seeds, and thus banana is usually propagated vegetatively. Banana is native to Malay and it seems to have been cultivated since ancient times in Indonesia (De Langhe et al., 2009). Plantain banana was introduced to Africa via West Africa, and the common or Asian type of banana was introduced via Madagascar (De Langhe et al., 2009) and Zanzibar (Simmonds & Shepherd, 1952).

Most of Uluguru banana accessions were clustered together in the cluster analysis, indicating genetic similarity. The resistance to current expanding disease resulted in selection of fewer varieties including '*Mtuike*'. Approximately 20 years ago, diverse banana varieties were cultivated in the Uluguru Mountains (Komatsu, 2006), although no genetic analyses of these varieties have been conducted. In addition, positive selection of commercially valuable banana varieties may have occurred. Generally, commercialization of agricultural production results in decreased numbers of leading cultivars and thus less genetic variation. This was

especially the case with the banana, which propagates vegetatively, and its genetic varieties converged rapidly, resulting in low genetic diversity. In contrast, banana accessions from the Northern Mountains of Tanzania were classified into various clusters, indicating high genetic diversity. The variety of uses of the banana in food in the Northern Mountains may explain the high genetic diversity. Java also had various genotype accessions; however, they are genetically similar despite being of different genotypes. This suggests that many different genotypes of banana were produced from limited resources. The lower banana diversity in Java compared with Tanzania may be due to the diversified uses of banana in Tanzania.

Bananas of the AAA genotype can be differed genetically depending on whether they are cooking or table fruit. Cooking varieties of the AAA genotype may have developed independently in Tanzania. Generally, cooking bananas are considered to have genome B (*M. bulbisiana*) lines. Development of the genome A (*M. acuminata*) line into a cooking banana variety in Tanzania may in part explain the genetic diversity of Tanzanian bananas.

CONCLUSION

The homegardens in the Uluguru Mountains were found to be different from those in other areas of Tanzania but similar to Java homegardens, especially in terms of the species grown. Although homegarden component species mostly originated in Asia and homegardens resulted in very similar between Uluguru and Java, the each species in Uluguru homegardens was not likely to be introduced from Java. Genetic analysis of the important homegarden component species such as mango, jackfruit, and banana indicated that they seem to be brought from different areas. The component tree species suggested to be introduced via various routes and at various times, and as a result, they composed together to produce a similar homegarden landscape to that found in Asia.

This research highlights the importance of trans-Indian Ocean trading. Genetic analyses indicated that jackfruit and most mango varieties differ from those in Java, but some Javanese mango varieties were similar to those in Tanzania. In Tanzania, banana is used for various purposes and is associated with a higher genetic diversity, despite the considerable genetic distance from its origin. Studies of East African highland banana (cooking banana of the AAA genotype) varieties will facilitate further identification of the factors influencing the genetic diversity of banana in East Africa.

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Photo 1. The Uluguru Mountains. The Luguru people have resided below 1,500 m asl. Over this altitude, natural forests are conserved for indigenous habitats (Feb./2003).

Photo 2. Jackfruit, mango, and banana accessions from Uluguru Mountains. Mango 'Bongwa' (top) is the most common local mango, usually very large tree while bearing small fruit, suggesting one of old varieties, but taste is acceptable. Banana 'Mtwike' (bottom left) is also major cultivar in the Uluguru Mountains, accounting for more than 90%, suggesting banana diversity in this area has been rapidly decreasing recently. Jackfruit (bottom right) has no variety (Feb./2017).

Photo 3. *Jalala* homegarden in the Uluguru mountain (left, Aug./2014) which are often located in slope and covered with tall tree crops, and *pekarangan* homegarden in Java (right, Apr./2013) often has fishpond and animal stocks. Despite of these differences, both the homegardens have very similar appearance.

Photo 4. Landscape of *jalala*, Uluguru homegarden. All trees can be seen are planted crops. Jackfruit, breadfruit, coco palm, mango, cinnamon, clove trees are observed. Natural trees are not remained in this landscape. Bare lands are crop fields (Aug./2014).

Photo 5. Banana collected from *jalala* to the market (top). Taro and banana (left), pepper and pineapple (right) and other small crops are planted on the floor of *jalala* (Feb./2017).